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CCMTA Load Security Research Project

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Report # 9

EFFECT OF CARGO MOVEMENT ON TENSION IN TIEDOWNS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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North American Cargo Securement Standard

CCMTA is serving to coordinate the development of a revised North American Cargo Securement Standard. To this end the research results in this report are being reviewed and discussed by interested stakeholders throughout North America.

Those readers interested in participating in the development of the North American Cargo Securement Standard through 1998 are invited to visit the project Web site at www.ab.org/ccmta/ccmta.html to secure additional project information.

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Abstract

A series of tests were conducted to determine the effect of longitudinal or lateral movement of an article of cargo placed lengthwise on a vehicle and secured by tiedowns transversely across the vehicle on the tension in those tiedowns.

Transverse tiedowns over an article of cargo provide almost no initial resistance to longitudinal or lateral cargo movement, and the resistance is not high even after significant cargo movement. Friction between the cargo and deck is the principal source of resistance to cargo movement. The tiedown can play a significant role in making that friction effective.

Recommendations are made for use of transverse tiedowns as part of the cargo securement system.

Executive Summary

A lack of understanding of the technical basis for existing regulations on cargo securement meant it was not possible to resolve differences between them to revise a cargo securement standard for Canada's National Safety Code. This process identified a number of research needs, which are now being addressed through the North American Load Security Research Project.

The work reported is a series of tests to determine the effect of longitudinal or lateral cargo movement on the tension of the transverse tiedowns of a typical heavy truck cargo securement system. It is outlined in Sections 8.5 and 8.6 of the project proposal.

A test rig was constructed with a wheeled carriage, representing a rigid article of cargo, that could be pulled on a track to represent movement of the cargo. Tiedowns could be secured over the carriage, either along or across the track, to represent respectively lateral or longitudinal movement of cargo on a vehicle. The carriage was pulled with various tiedown angles and initial tiedown tensions, for both chain and webbing tiedowns, with various corners on the carriage representing different types of cargo.

Tension in a transverse tiedown securing cargo loaded longitudinally on a vehicle is governed principally by the geometric effect of cargo movement, which causes elongation of the tiedown. Such tiedowns provide very little initial resistance to either longitudinal or lateral movement of the cargo. Resistance develops as the cargo moves, but only reaches the range 0.1-0.25 g after significant cargo movement, in the range 10-46 cm (4-18 in). Transverse tiedowns over an article of cargo therefore do not by themselves provide either direct or effective securement. They can increase the pressure of the cargo on the deck, increasing frictional resistance. However, this effect is relatively marginal if there is not a large tiedown angle and a high tiedown initial tension. It is also not reliable, as tiedown tension may not be maintained at its initial value during a trip. The relationship between the tiedown and the corner of the cargo or dunnage over which it passes may play a significant role in the behaviour of the securement system.

It is recommended that cargo placed longitudinally on the deck of a vehicle and secured by transverse tiedowns should preferably be immobilized, and if this is not possible, the coefficient of friction between the cargo and deck or interface should be increased to reduce any tendency to shift. The initial tiedown tension should be as high as possible, preferably at least 50% of the tiedown working load limit, to gain the maximum benefit from friction between the cargo and the deck. Corner protection should be used where a hard tiedown would bear directly onto cargo or dunnage that may be crushed if the cargo moves. The way in which transverse tiedowns work should be clearly explained to those that use them, so that they be understood and used effectively.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report.

Acknowledgments

The work reported here is part of the Load Security Research Project conducted on behalf of the Canadian Council of Motor Transport Administrators (CCMTA) by Strategic Transportation Research Branch of Ontario Ministry of Transportation. This section recognizes the direct contributions of those who organized and conducted this part of the work. It also recognizes that there have been many indirect contributions by others.

The project was funded jointly by the following :

- Alberta Transportation and Utilities;
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The project was conducted under the guidance of the Load Security Research Management Committee, formed by CCMTA and composed of one representative of each of the funding partners and chaired by Mr. M. Schmidt of Federal Highway Administration, Albany, New York. Sean McAlister provided administrative support from CCMTA.

The test rig was designed by Walter Mercer, and the work was conducted by Norm Carlton, Gary Giles, Walter Mercer, Bill Stephenson and Mike Wolkowicz of Strategic Vehicle Technology Office of MTO.

Some of the tiedown equipment used in these tests was donated by Kinedyne Canada Ltd for the project.

1/ Introduction

Heavy truck cargo securement is a matter of public safety, subject to a body of industry practice and government regulation. Regulations are broadly similar across North America's many jurisdictions, but there are also some significant differences. When the Canadian Council of Motor Transport Administrators (CCMTA) came to revise a cargo securement standard for Canada's National Safety Code, a lack of understanding of the technical basis for existing regulations made it impossible to resolve differences between them, and a number of research needs were identified. Ontario Ministry of Transportation prepared a draft proposal for this research that was widely circulated for review through governments and industry. The proposal was revised and became the work statement for the North American Load Security Research Project [1]. This has three objectives :

- To determine how parts of cargo securement systems contribute to the overall capacity of those systems;
- To demonstrate the adequacy of parts, and the overall capacity, of cargo securement systems; and
- To develop principles, based on sound engineering analysis, that could contribute to an international standard for cargo securement for heavy trucks.

The goal is to supplement existing practice with these research findings, and to develop uniform North America-wide standards for cargo securement and inspection.

Many typical articles of cargo are placed on the deck of a truck, and secured only by transverse tiedowns that are attached to one side of the truck, pass over the cargo, and are initially tensioned then locked on the other side. If the truck brakes, the cargo tends to slide forward. If the truck drives in a curve, the cargo tends to slide sideways, moving laterally under the tiedowns. Such movement affects the length of the spans of the tiedown, hence the tension in the tiedown. The purpose of this series of tests was to determine the effect of lateral or longitudinal movement of a rigid article of cargo secured by transverse tiedowns on the tension in its tiedowns. The work reported here was outlined in Sections 8.5 and 8.6 of the project proposal [1].

2/ Test Program

2.1/ Objective

The objective of this test is to determine the effect of lateral or longitudinal cargo movement on tension in the tiedowns of a typical heavy truck cargo securement system.

2.2/ Scope

The cargo was represented by a wheeled carriage that could be pulled along a track, so that friction was minimized, and could be secured with tiedowns either transverse or parallel to the track. Motion of the carriage along the track therefore represented either longitudinal or lateral motion of an article of cargo secured with transverse tiedowns.

These tests were not concerned with the tiedowns themselves. Chain and synthetic webbing tiedowns with a relatively high strength were therefore selected, to allow greater carriage movement within the strength capacity of the tiedowns.

The tiedowns were tightened initially to one of three different tensions:

1/ low, 5% of tiedown working load limit (WLL);
2/ moderate, 20% of tiedown WLL; and
3/ high, 50% of tiedown WLL.

Three different tiedown angles were used, measured between the tiedown and the floor:

1/ 45 deg;
2/ 60 deg; and
3/ 80 deg.

Tests were conducted using three different configurations of corner on the carriage:

1/ round steel;
2/ 90 deg steel; and
3/ 90 deg wooden.

3/ Procedures

3.1/ Test Apparatus

The tests were conducted on the rig shown in Figure 1. A short track was attached to the 2.4 m (8 ft) square bed, and a wheeled carriage about 1.75 m (69 in) high and 1.22 m (4 ft) square ran on the track to represent an article of cargo. A hydraulic actuator was attached to the bed, and a drawbar attached between the actuator and the front of the carriage was used to draw it along the track. The actuator had a stroke of about 0.46 m (18 in), a load capacity of about 40 kN (9,000 lb), and was controlled to pull at a constant speed of about 8.31 mm/s (0.33 in/s). The test rig allowed two tiedowns to be attached parallel to the direction of pull, as shown in Figure 2, which represents lateral motion of cargo secured to a vehicle by transverse tiedowns, and is referred to as a lateral pull. It also allowed two tiedowns to be attached perpendicular to the direction of pull, as shown in Figure 3, which represents longitudinal motion of cargo secured to a vehicle by transverse tiedowns, and is referred to as a longitudinal pull. Guides could be attached to the upper corners of the carriage to represent circular steel, square steel and square wood corners for the cargo.

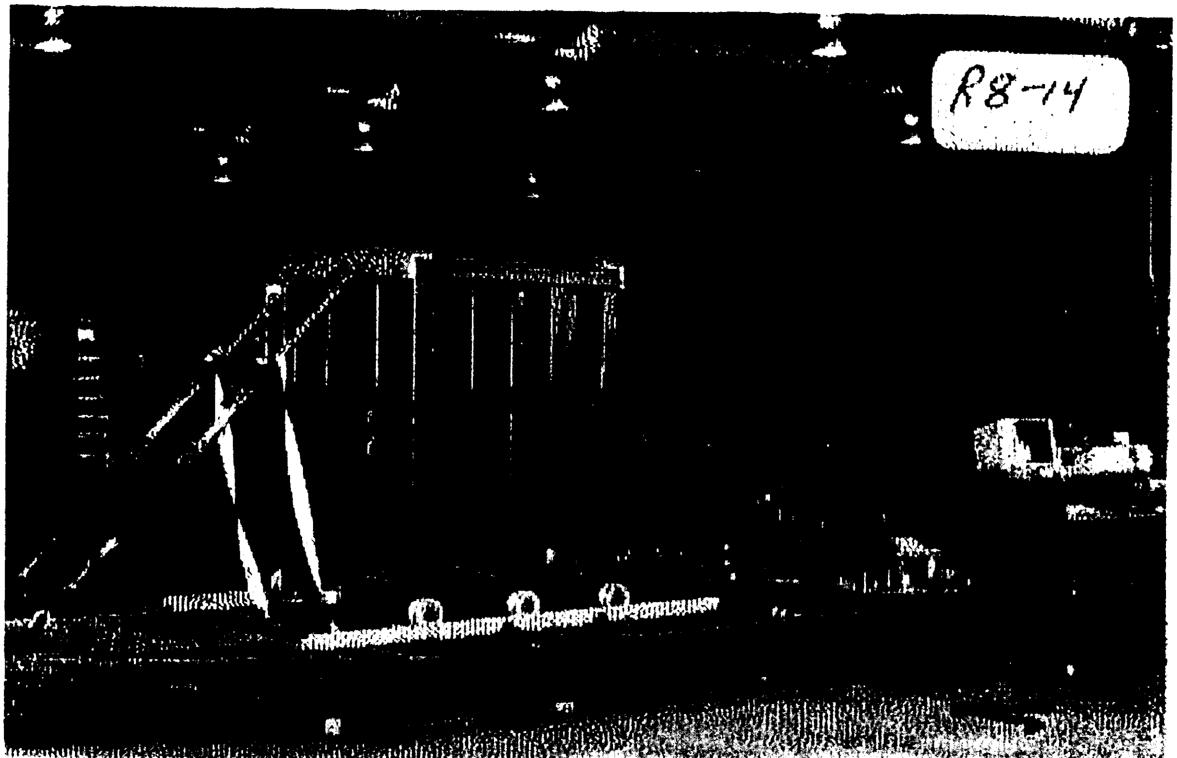


Figure 1/ General View of Test Rig and Data Acquisition System

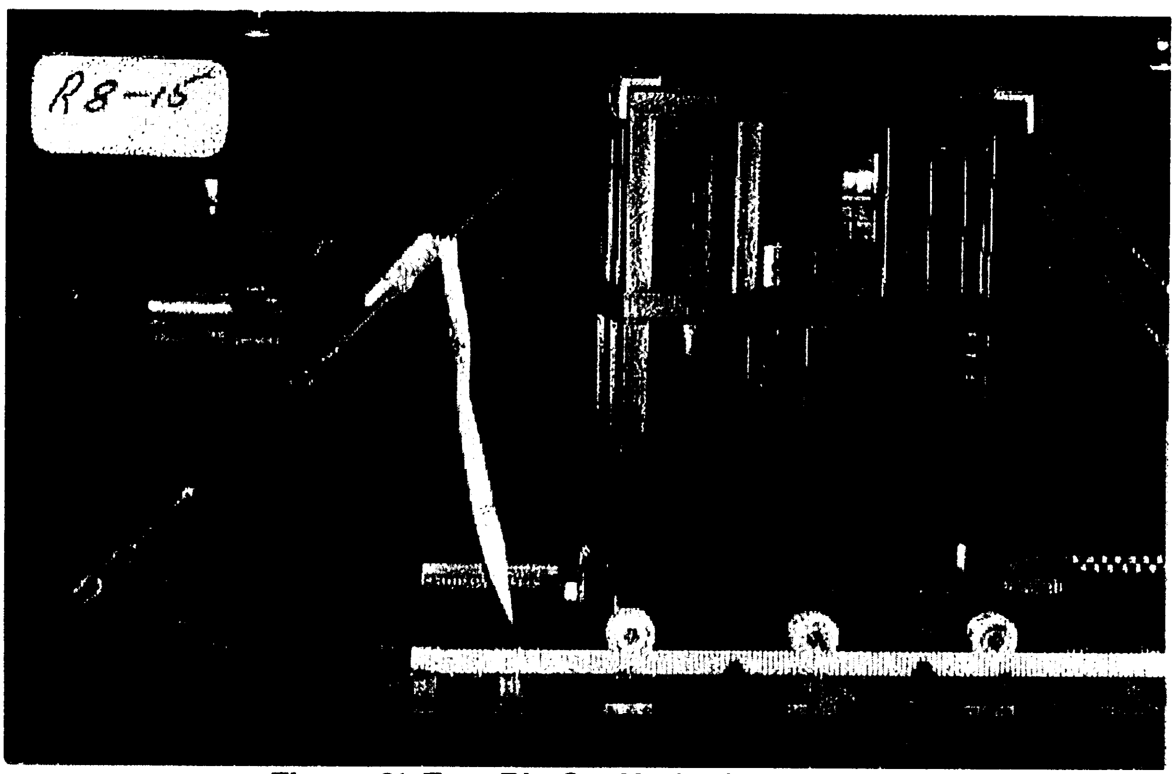


Figure 2/ Test Rig Set Up for Lateral Pull

Figure 3/ Test Rig Set up for Longitudinal Pull

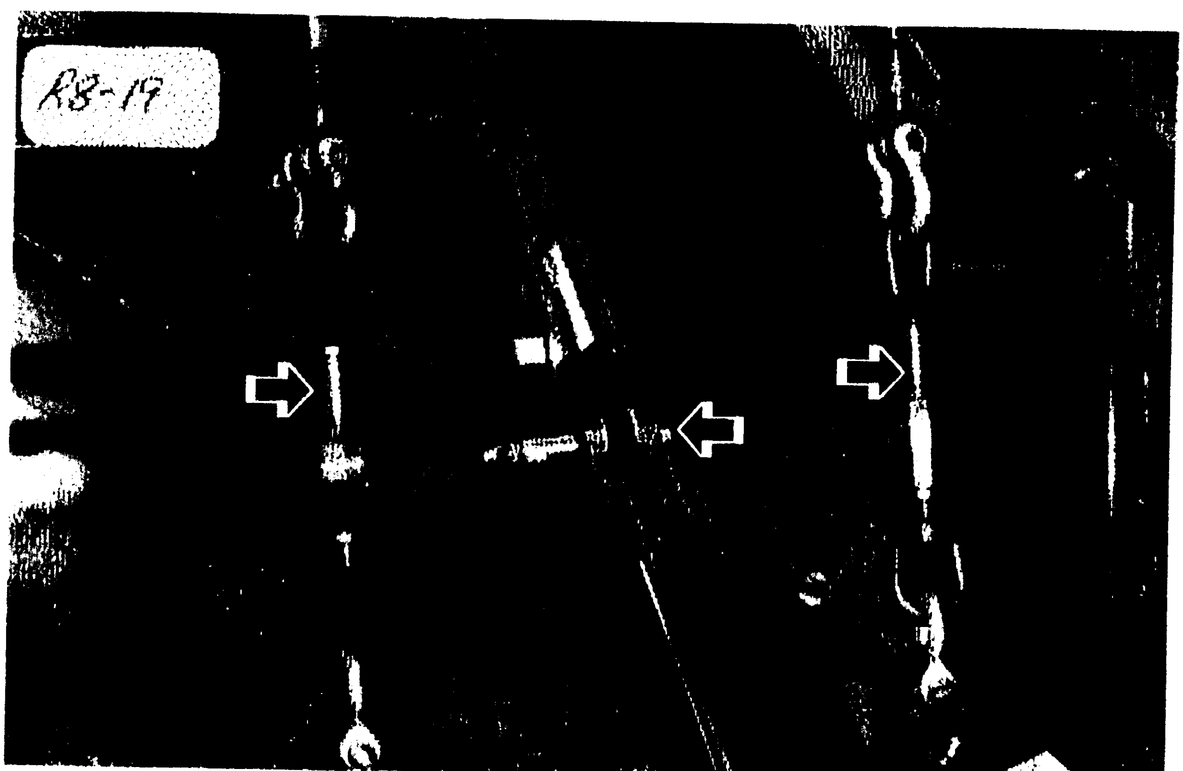


Figure 4/ Drawbar Load Cell and Tiedown Tension Sensors

The carriage was designed simply to run on the tracks. However, extreme tension in the tiedowns near the end of a longitudinal pull tended to cause the nose of the carriage to pitch up. The track was therefore modified with a reaction rail above the front wheels of the carriage, which prevented these wheels from lifting off the track, and a concrete block weighing about 907 kg (2,000 lb) was placed in the front of the carriage as a ballast weight. The reaction rail and concrete block are both seen in Figure 3.

Two types of tiedown were used :

1/ 5/16 in Crosby Spectrum 8 (grade 8) chain, with a working load limit (WLL) of 2,041 kg (4,500 lb); and
2/ 3 in Kinedyne webbing, with a WLL of 1,814 kg (4,000 lb), and a California Highway Patrol rating of 4,082 kg (9,000 lb).

3.2/ Instrumentation and Data Capture

A Strainsert model CPA-1.25 (SS)X0 clevis pin load sensor, rated at 80.096 kN (18,000 lb), was used to measure the tension in the drawbar, shown in Figure 4 joining the drawbar and actuator at the left-pointing arrow. A Unimeasure model P510-20 pull cord transducer was attached to the bed, and its cord was extended and attached to the carriage to measure its forward motion. A Strainsert Model SJ-F8 Type H load sensing stud, rated at 66.75 kN (15,000 lb), was attached in series with each tiedown on each side of the carriage, to measure the tension in that span of the tiedown, as also seen in Figure 4 at the right-pointing arrows. Data from these six instruments was captured into a PC-based data acquisition system at a sample rate of 10 Hz per channel, which was quite fast enough given the relatively low speed of the drawbar pull.

It was possible in some tests that the tiedown tensions could increase extremely rapidly, leading to risk of a broken tiedown, and a potential safety hazard. An electronic comparator was therefore designed and built to monitor the four tiedown tensions continuously during a test, and to shut down the hydraulic actuator if any tiedown tension exceeded about 44.5 kN (10,000 lb), which is just over twice the working load limit of each type of tiedown.

3.3/ Test Procedure

Preliminary tests were conducted to determine the rolling friction of the carriage, and the stiffness of the tiedowns.

For each test series, the carriage was sitting on the track, the load pins were attached to the deck of the test rig by heavy duty shackles, and the test corners were bolted to the upper edge of the carriage.

For a particular test run, the carriage was pushed back on the track to full extension of the hydraulic actuator, and was adjusted to relieve any tension in the drawbar. The two tiedowns were put loosely in place, and were attached to the load pins on each side by a ratchet binder. Each binder was then tightened to the desired tiedown tension. This usually took some time, as adjusting one tension affected the others, which then required further adjustments. In addition, with webbing tiedowns, there was a tendency for the tiedown to relax and lose tension, and it was necessary to wait, re-tighten, and wait again, repeating this process until all tensions finally stabilized. When the tensions were set, the pull cord was attached to the carriage.

The transducer outputs were zeroed. The data acquisition system was started, and a three point calibration (zero, half-scale and full-scale) was recorded, followed by at least three seconds of zero data. Data acquisition was then stopped while final preparations for the test run were made. When all was ready, data acquisition was re-started, and about three seconds later the hydraulic system was actuated to draw the carriage forward. The pull continued until either it was shut down automatically because of an elevated tiedown tension, or the actuator reached its maximum load capacity, or the actuator reached its full stroke. At this point the hydraulic system was stopped, and data acquisition was also stopped. The hydraulic actuator was then momentarily reversed, to relieve the drawbar tension somewhat, the pull cord was detached from the carriage, and the ratchets were reversed to relieve the tension in the tiedowns.

The data in the PC memory were saved to a file on the computer's hard disk. The data were retrieved, the calibrations were examined, and were adjusted if necessary. A quick look at the data was taken to ensure that the results were reasonable. If there was any question, the run was repeated, and sometimes adjustments were made to test conditions or fittings to ensure consistent and repeatable data. The file was then saved again, and a backup file was also saved immediately on a floppy disk.

Samples of equipment and test activity were recorded on video tape. Colour still photographs and slides were taken of the tests, instrumentation and test activity. A detailed log of test activities and observations was maintained.

3.4/ Data Processing

The data file from each run was simply calibrated and de-trended in a specialized test data processing program written at MTO. Key results and values were extracted manually, entered in a spreadsheet program, and were summarized in tables and graphical form for this report.

3.5/ Test Matrix

The scope identifies two tiedown directions, two types of tiedown, three tiedown tensions, three tiedown angles, and three corners. All combinations of these were tested, for a total of 108 conditions. All combinations of tiedown tension, tiedown angle and corner are shown in Table 1 below. The same matrix was used for longitudinal and pulls, for each type of tiedown.

Table 1/ Test Matrix

Initial tension (% WLL)			Tiedown angle (deg)			Corner		
5	20	50	45	60	80	Round	Square	Wood
X			X			X		
X			X				X	
X			X					X
X				X		X		
X				X			X	
X				X				X
X					X	X		
X					X		X	
X					X			X
	X		X			X		
	X		X				X	
	X		X					X
	X			X		X		
	X			X			X	
	X			X				X
	X				X	X		
	X				X		X	
	X				X			X
		X	X			X		
		X	X				X	
		X	X					X
		X		X		X		
		X		X			X	
		X		X				X
		X			X	X		
		X			X		X	
		X			X			X

4/ Results

4.1/ Rolling Resistance of the Carriage

A preliminary test found that the average rolling resistance of the carriage over a complete pull was about 0.48 kN (107 lb). The carriage, concrete block and fittings together weighed about 1,680 kg (3,700 lb). If it is assumed that the vertical components of tiedown tension provide an effective increase in carriage weight and result in a proportionate increase in rolling resistance, the effect of rolling resistance is estimated to increase drawbar pull by no more than 5% over that due directly to the tiedowns.

4.2/ Tiedown Stiffness

Preliminary tests were also conducted to determine the stiffness of the 5/16 in chain and 7.5 cm (3 in) webbing used in this series of tests. Figure 5 shows chain tension against tiedown extension, for a piece of chain 105 links or 2.883 m (113.5 in) long. This gives a chain stiffness of about 52,370 kN/m/link (743,925 lb/in/link). Figure 6 shows webbing tension against tiedown extension, for a piece of 3 in webbing 2.241 m (88.25 in) long, with a 21.5 cm (8 in) seam at one end. It shows two cases, one where the webbing was stretched and released, and another where the webbing was held at maximum extension. The stretch and release gives a webbing stiffness of about 8,022 kN/m/m (114,407 lb/in/in). However, when the webbing was stretched and held, the tension gradually diminished, and after about 10 minutes it had dropped by about 12-15%. Similar behaviour for synthetic webbing was encountered in another test conducted in this series [2].

4.3/ Lateral Pulls

Figure 7 shows a typical pull, with a chain tiedown at an initial tension of 20% of tiedown working load limit with a 60 deg tiedown angle on square steel corners. This shows the near side increases somewhat in tension, so the tiedown is slipping over the carriage to minimize the difference in tension as the tension on the far side increases substantially. The shape of the tension curves is due to the nonlinear relationship of tiedown extension to carriage movement, due to the geometric arrangement of the tiedown. The bumps are due to the chain stretching and twisting, then relaxing, as individual links slide across the corner. This characteristic was evident for the square steel and wood corners, while the chain slid smoothly across the round steel corner.

Figure 8 shows a typical pull, also for webbing tiedowns at an initial tension of 20% of tiedown working load limit with a 60 deg tiedown angle on square steel corners, that is directly comparable to Figure 7. The tensions of the webbing tiedown exhibit continuous notches, due to small slips across the top of the carriage and back along its length. With webbing tiedowns, all tests were terminated due to the travel available to the carriage. Those with tiedown angles of 45 and 60 deg were terminated when the

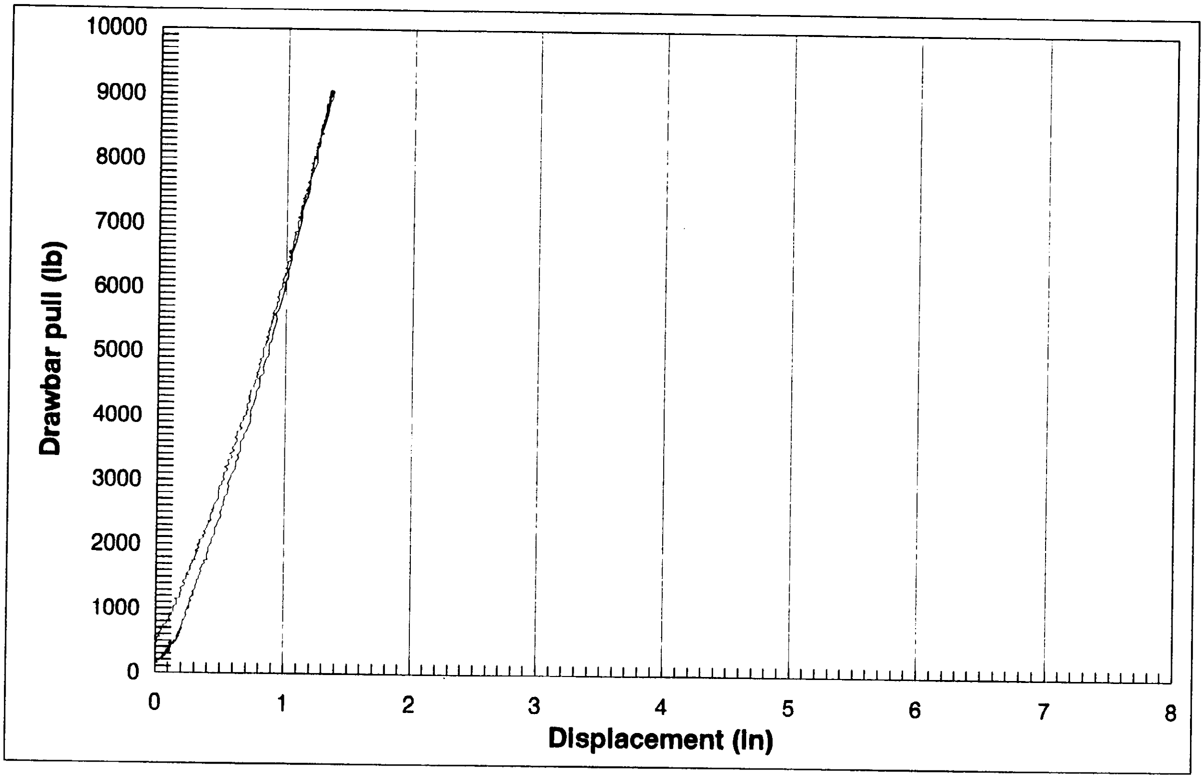


Figure 5/ Pull of 5/16 in grade 8 chain 2.883 m (113.5 in) long, 105 links

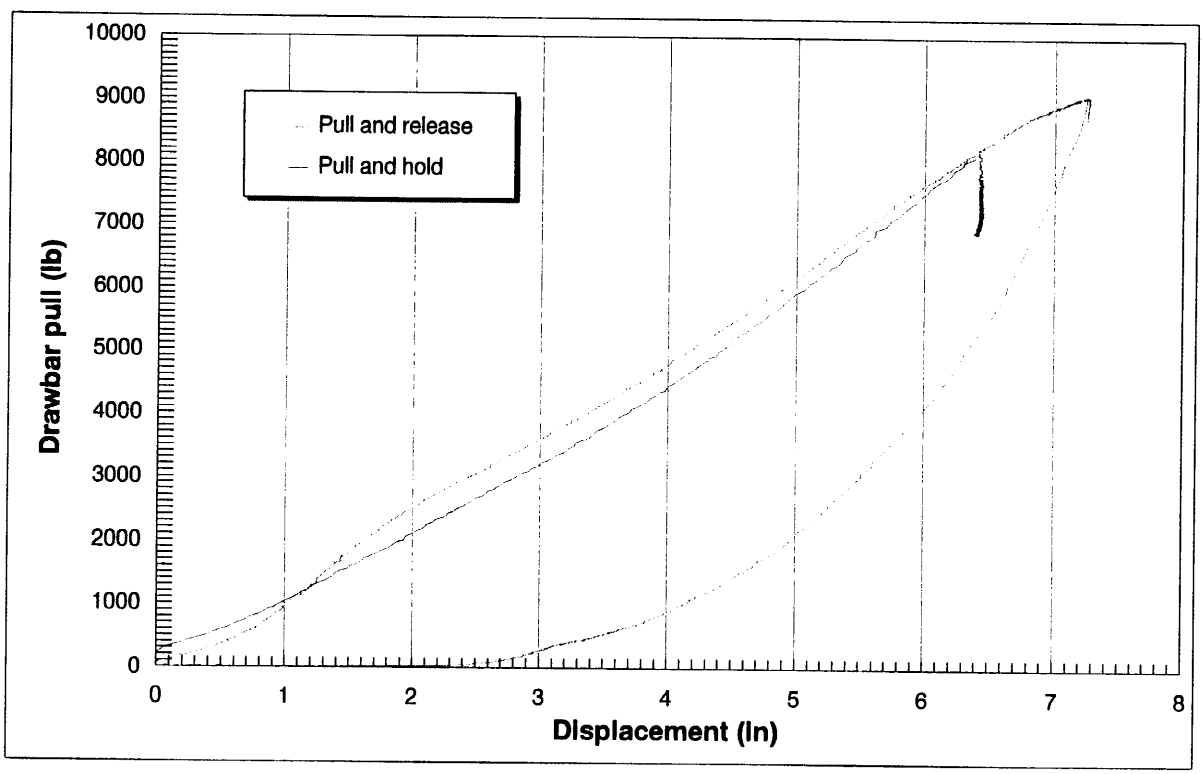


Figure 6/ Pulls of 3 in webbing 2.242 m (88.25 in) long

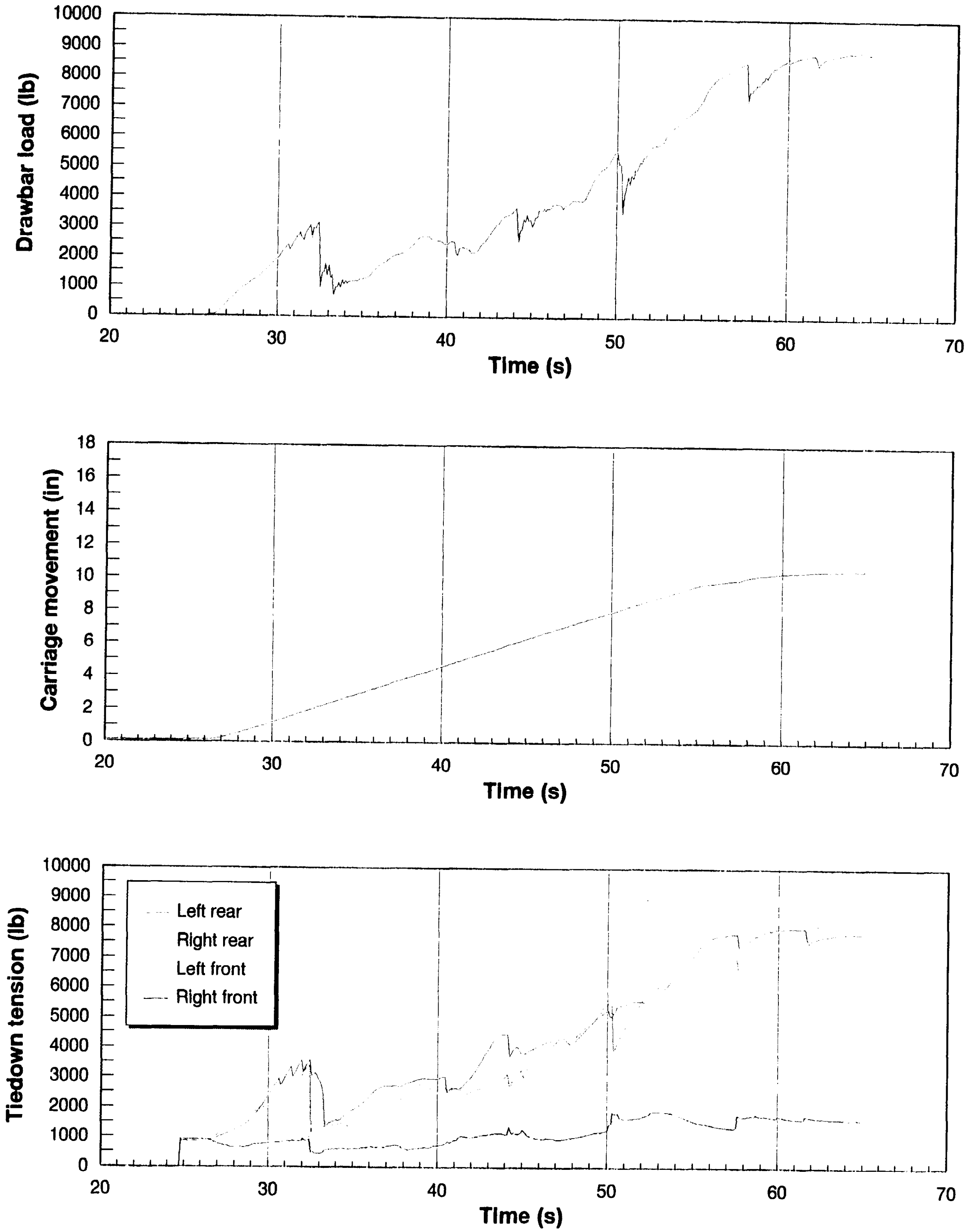


Figure 7/ Lateral pull with two 5/16 in grade 8 chain tiedowns
60 deg tiedown angle with 20% WLL initial tension and square steel corners

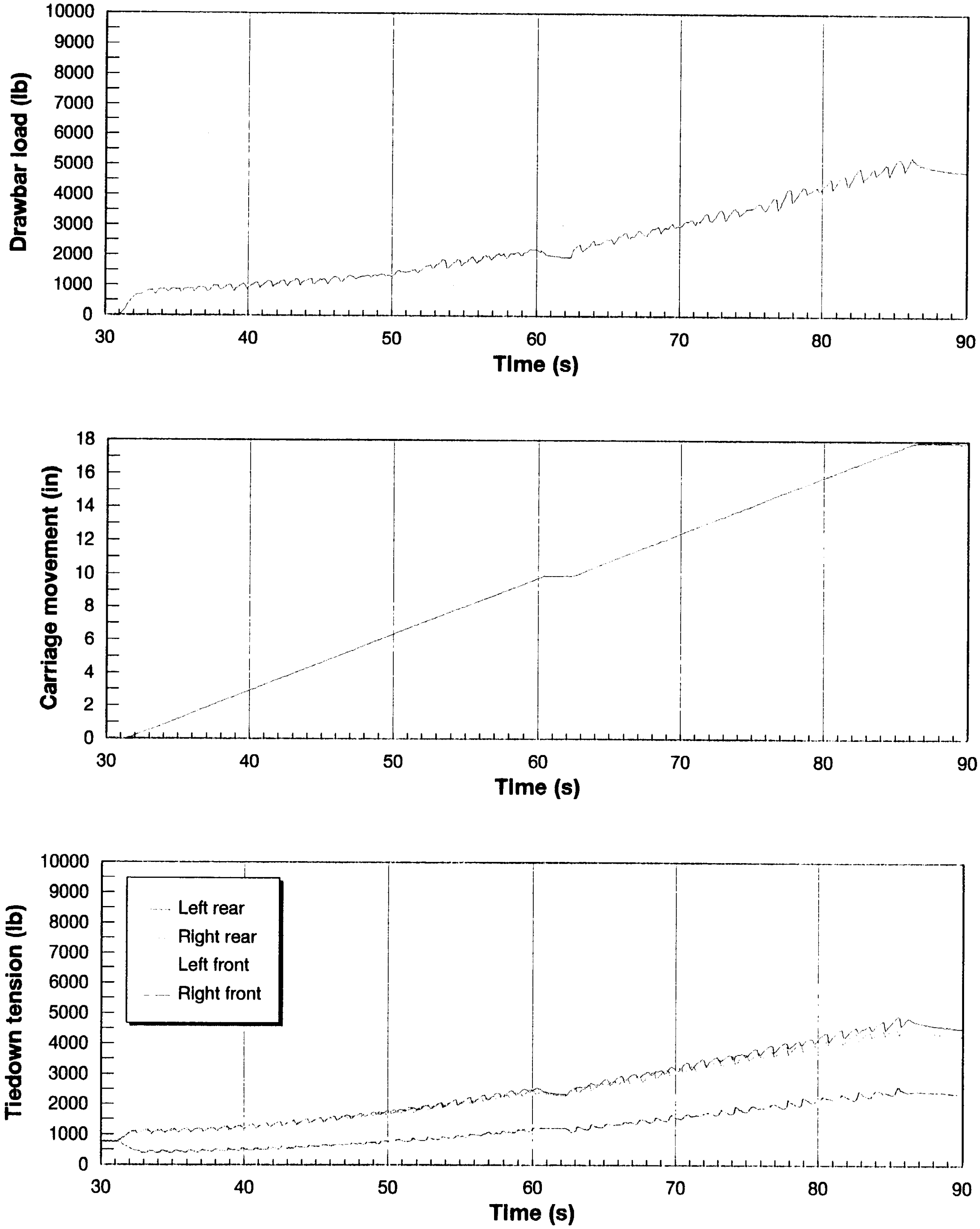


Figure 8/ Lateral pull with two 3 in webbing tiedowns
60 deg tiedown angle with 20% WLL initial tension and square steel corners

actuator reached its full stroke of about 46 cm (18 in), and tests with a tiedown angle of 80 deg were terminated after 25-28 cm (10-11 in) of travel when the front tiedown was near-vertical and impeding further movement of the carriage. Tiedowns slipped continuously during a pull.

The drawbar pull is equivalent to the resistance provided by rolling resistance of the carriage and tension in the tiedowns. Figures 7 and 8 show that the cargo starts moving as drawbar pull force is developed. With the very low rolling resistance of the carriage, the tiedowns therefore provide almost no initial resistance to cargo movement. These Figures also show that resistance does develop as the cargo moves, because the tension is increasing in the spans of the tiedowns. The increase in tension in the tiedowns with cargo movement does two things. It increases the friction between the tiedowns and the cargo, which provides a direct resistance to the cargo motion. The vertical component of tiedown tensions also acts on the article to increase its pressure on the deck of the vehicle, and would provide an effective increase in the coefficient of friction between the cargo and the deck. While the resistance did increase, it was often not significant until the cargo had moved a significant distance, of the order of 15-25 cm (6-10 in).

Table 2 is a summary of the results for lateral pulls with chain tiedowns, and Table 3 is the corresponding summary for webbing tiedowns, in the same format.

The first three columns present the test conditions, in accordance with Table 1. The fourth column identifies the reason the data were selected, either because a tiedown reached its working load limit (WLL), or the actuator reached its maximum stroke or the front tiedown prevented further motion of the carriage (max). The next three columns present the pull force, carriage movement and highest tiedown tension, either at the moment the first tiedown reached its working load limit, or if no tiedown reached that limit, then when the highest tension occurred in any tiedown during the pull. In the latter case, if the tiedowns were slipping across the carriage, the highest tiedown tension did not necessarily occur at the end of the pull. Note that the tensions in the two rear spans were relatively close, and those in the front two were also relatively close, but significantly less, as seen in Figures 7 and 8. The final column represents the equivalent external acceleration for the heaviest article of cargo that could be secured under current regulations using the two tiedowns used in this test [3]. This is 8,165 kg (18,000) lb for the 5/16 chain, and 7,258 kg (16,000 lb) for the 3 in webbing tiedowns. The value given is obtained simply by dividing the pull force by 18,000 or 16,000 lb, as appropriate for the tiedown. Note that not only is this resistance relatively modest, it is also not developed until the cargo has moved a substantial distance, 10-46 cm (4-18 in), during which time the cargo will also have developed some velocity.

Most tests with a tiedown angle of 80 deg were terminated after 25-28 cm (10-11 in) of travel with the front tiedown near-vertical and impeding further forward movement of the carriage.

Table 2/ Lateral Pull for 5/16 in grade 8 Chain Tiedowns

Tiedown angle (deg)	Corner	Initial tension (lb)	Stop	Pull force (lb)	Shift (in)	Tiedown tension (lb)	Pull equiv. g
45	R	225	WLL	4138	15.59	4500	0.230
45	R	900	WLL	3912	13.11	4507	0.217
45	R	2250	WLL	3553	9.04	4519	0.197
45	S	225	WLL	5103	13.55	4552	0.284
45	S	900	WLL	4032	11.29	4543	0.224
45	S	2250	WLL	5457	8.34	4527	0.303
45	W	225	WLL	4983	16.34	4504	0.277
45	W	900	WLL	5309	14.79	4501	0.295
45	W	2250	WLL	5554	11.16	4514	0.309
60	R	225	WLL	3759	9.87	4522	0.209
60	R	900	WLL	3726	8.33	4551	0.207
60	R	2250	WLL	2994	5.77	4523	0.166
60	S	225	WLL	4383	7.70	4520	0.244
60	S	900	WLL	4600	7.52	4548	0.256
60	S	2250	WLL	3285	1.68	4525	0.183
60	W	225	WLL	4998	16.34	4504	0.278
60	W	900	WLL	4596	11.63	4501	0.255
60	W	2250	WLL	4351	10.25	4504	0.242
80	R	225	WLL	2566	7.37	4549	0.143
80	R	900	WLL	2167	5.94	4525	0.120
80	R	2250	WLL	1804	3.78	4523	0.100
80	S	225	WLL	2230	5.51	4543	0.124
80	S	900	WLL	2179	4.58	4561	0.121
80	S	2250	WLL	1755	3.00	4502	0.098
80	W	225	max	2245	10.65	3396	0.125
80	W	900	WLL	3026	10.19	4530	0.168
80	W	2250	WLL	2895	8.45	4514	0.161

Note : R=round steel corner, S=square steel corner, W=square wood corner.

Table 3/ Lateral Pull for 3 in Webbing Tiedowns

Tiedown angle (deg)	Corner	Initial tension (lb)	Stop	Pull force (lb)	Shift (in)	Tiedown tension (lb)	Pull equiv. g
45	R	200	max	1709	17.74	1781	0.107
45	R	800	max	2333	17.88	2756	0.146
45	R	2000	WLL	3629	17.59	4023	0.227
45	S	200	max	2211	17.88	1906	0.138
45	S	800	max	2976	17.84	2618	0.186
45	S	2000	max	3875	17.76	3985	0.242
45	W	200	max	1677	17.87	1732	0.105
45	W	800	max	2474	17.85	2483	0.155
45	W	2000	WLL	3126	17.30	4006	0.195
60	R	200	max	3835	12.85	3532	0.240
60	R	800	WLL	3901	15.53	4026	0.244
60	R	2000	WLL	3292	11.09	4018	0.206
60	S	200	max	3849	17.91	3432	0.241
60	S	800	WLL	4133	14.99	4005	0.258
60	S	2000	WLL	3620	11.24	4040	0.226
60	W	200	WLL	3938	17.66	4011	0.246
60	W	800	WLL	3938	15.97	4010	0.246
60	W	2000	WLL	3120	10.30	4013	0.195
80	R	200	max	1868	11.10	2587	0.117
80	R	800	max	2629	11.23	3846	0.164
80	R	2000	WLL	2347	11.09	4008	0.147
80	S	200	max	1796	10.51	2439	0.112
80	S	800	WLL	2958	10.98	4014	0.185
80	S	2000	WLL	2369	7.34	4023	0.148
80	W	200	max	2318	11.24	2838	0.145
80	W	800	max	2862	11.00	3670	0.179
80	W	2000	WLL	2467	8.19	4012	0.154

Note : R=round steel corner, S=square steel corner, W=square wood corner.

With webbing tiedowns, all tests were terminated due to the travel available to the carriage. Those with tiedown angles of 45 and 60 deg were terminated when the actuator reached its full stroke, and tests with a tiedown angle of 80 deg were terminated after 25-28 cm (10-11 in) of travel when the tiedown was near-vertical and impeding further movement of the carriage. The webbing slipped continuously over all three types of corner.

With chain tiedowns, some tests were terminated when the rear tiedowns reached twice their working load limit, some when the actuator reached its maximum capacity, and some when it reached its full stroke. The chain slipped smoothly over the round steel corner. It simply sawed through the hardwood corner, as shown in Figure 9. Links caught on the edge of the square steel corner, and caused high drawbar loads which relaxed as the link passed around the corner. The chain also twisted as each link passed the corner, which also tended to increase the tension. Damage to the corners is shown in Figure 10. The rear corner was more severely gouged, because the tension was higher on that side. These effects would be expected from the data shown in Figure 7.

The effect of initial tension is best seen in Table 2 for the chain tiedown on round corners. As the initial tension is increased, the amount of movement to reach the tiedown working load limit is reduced, and the drawbar pull necessary to reach that limit is reduced. This works out because the chain slid smoothly over the corner. The results on the two other corners were affected by links catching on the corner, which produced significant deviations in drawbar pull and tiedown tension from the smooth pull for the round corner. It is quite evident from Figure 7 that the point in the pull where the tiedown tension just reaches the working load limit depends as much on the way a link passes the corner as it does on the movement of the carriage. The effect of initial tension is masked for the webbing results in Table 3, because they are taken for inconsistent points during the pull.

The resistance provided by the tiedown is of interest. There was very little initial resistance, as the carriage was designed to provide minimal rolling resistance. For a tiedown angle of 80 deg, which is an angle that would arise for cargo nearly the full width of the truck deck, the resistance was in the range 0.10-0.15 g, which was not developed until after 10-25 cm (4-10 in) of cargo movement. It is clear that transverse tiedowns over cargo loaded longitudinally on a vehicle provide little resistance to lateral motion, so cargo will tend to slide laterally in a turn in the absence of other sources of resistance. Other tests in this program have found coefficients of friction between common articles of cargo and common deck materials that are sufficient to ensure that cargo will be unlikely to shift at the acceleration levels common in normal driving [4]. However, where low coefficients of friction exist, cargo will be prone to shift, and the transverse tiedowns will do little to resist that shift. In such cases, either the coefficient of friction could be increased by use of rubber mats [4], or the cargo could be immobilized by blocking.

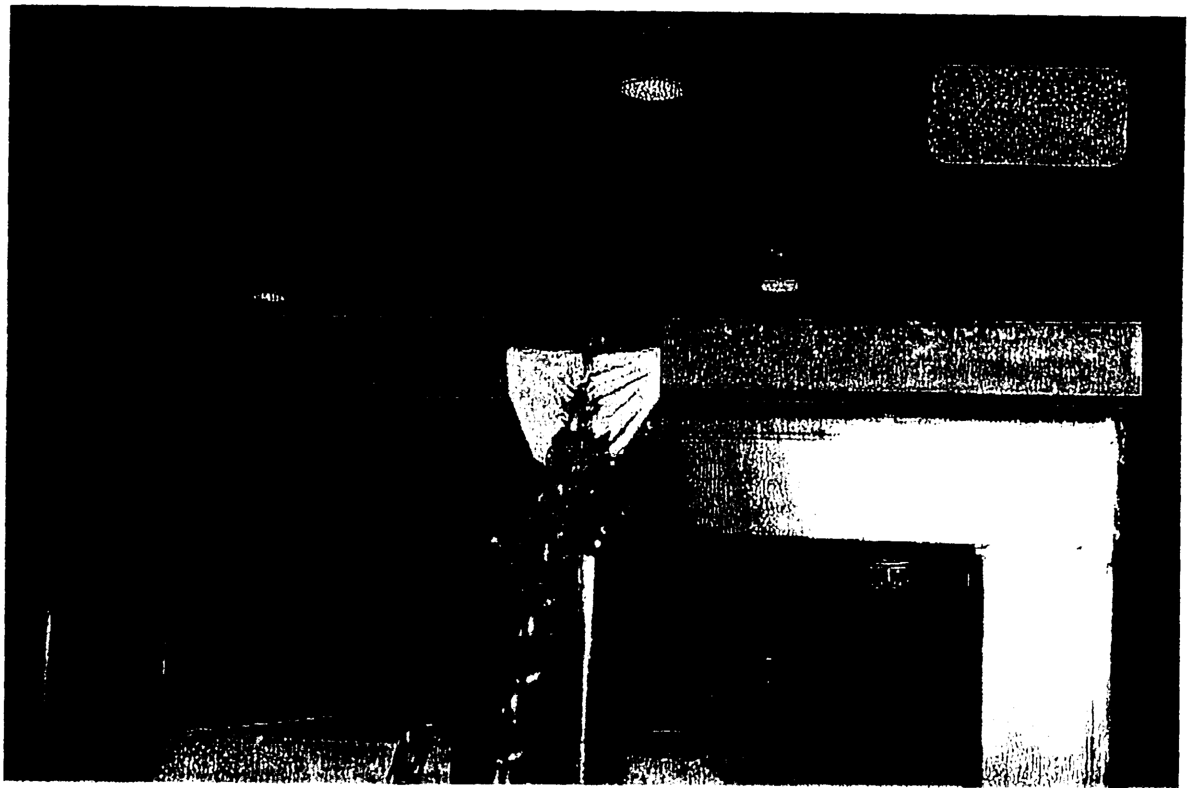


Figure 9/ Wood Corner Damaged by Chain after Lateral Pull

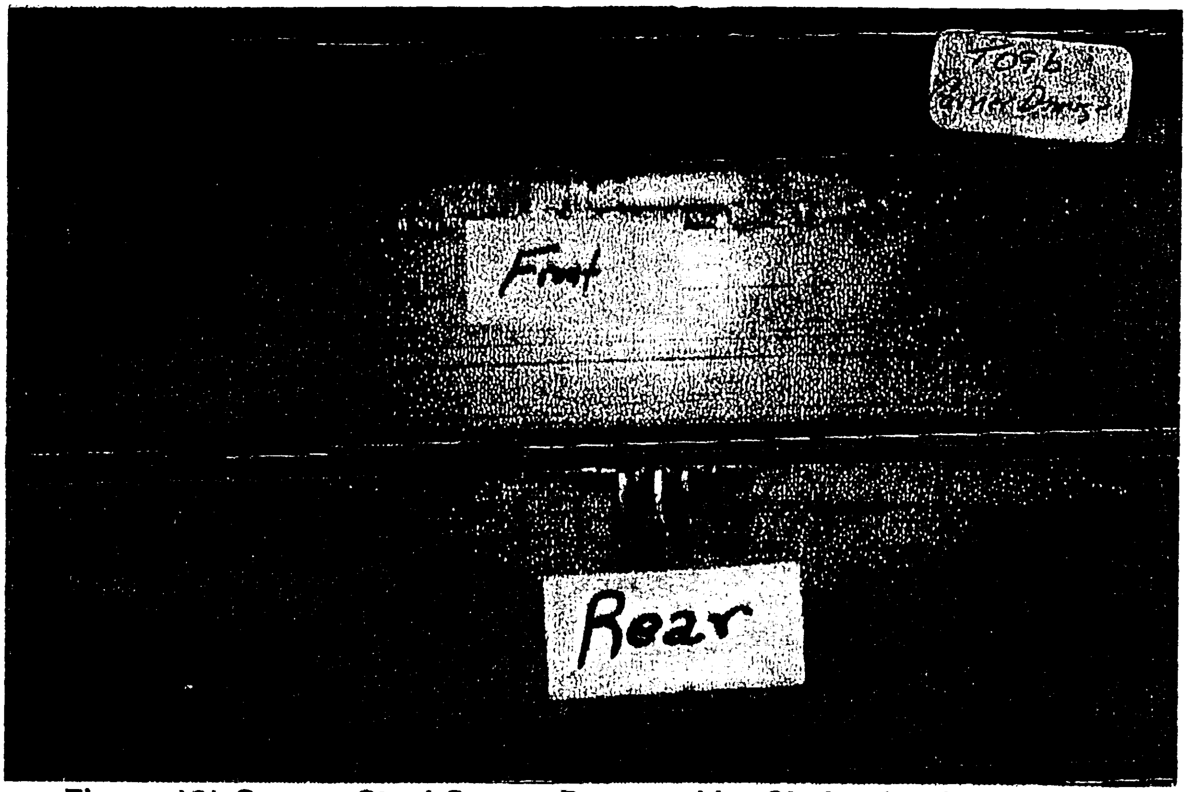


Figure 10/ Square Steel Corner Damaged by Chain after Lateral Pull

4.4/ Longitudinal Pulls

Figure 11 shows a typical pull and push back to the initial position for chain tiedowns at an initial tension of 20% of tiedown working load limit with an 80 deg tiedown angle on round steel corners. This shows a near-elastic response, with all four tensions tracking each other closely, due to the symmetric nature of the pull. All tensions returned close to the initial value, with the small difference likely due to a small change in orientation and indentation of the links that contact the corner on the carriage. The shape of the tension curves is due to the nonlinear relationship of tiedown extension to carriage movement, and the geometric arrangement of the tiedown. Almost all these tests were terminated when the tiedowns reached twice their working load limit. Those that were terminated due to the limited stroke of the hydraulic actuator would have been terminated by tiedown tension if the actuator stroke had been slightly greater. With chain tiedowns, regardless of the other parameters, the chain dimpled the corners or bit into the wood corner, and in most cases did not slip along the corner as the carriage moved, but were carried with it. Where there was slip, it was small.

Figure 12 shows a typical pull and push back to the initial position for webbing tiedowns at an initial tension of 20% of tiedown working load limit with an 80 deg tiedown angle on round steel corners. It is directly comparable to Figure 11. The tensions of the webbing tiedowns exhibit continuous notches during the pull, likely due to small slips of the tiedowns across the top of the carriage to accommodate stretch of the tiedown, and longitudinally back along the carriage. At the end of the pull, the tiedowns had slipped 6-25 mm (0.25-1 in) back along the carriage. When the carriage was returned to its original position, the slip and stretch of the tiedowns resulted in all tensions returning almost to zero while the carriage was still about 10 cm (4 in) from its initial position. It seems likely that the carriage could have been pulled right out from under the rearmost tiedown if the actuator stroke had been long enough. Webbing tiedowns always slipped back on the carriage, regardless of the corner, and all tests were terminated when the actuator reached its full stroke. Tiedowns often slipped several times during a pull, and slip of 15 cm (6 in) was observed in some cases.

The drawbar pull is equivalent to the resistance provided by the tiedowns. Figures 11 and 12 show that the cargo starts moving as soon as drawbar pull force is developed. In the virtual absence of friction, the tiedowns are seen to provide almost no initial resistance to cargo movement. These Figures also show that resistance does develop as the cargo moves, because the tension is increasing in the spans of the tiedowns. The increase in tension in the tiedowns with cargo movement does three things. It increases the friction between the tiedowns and the cargo, which provides a direct resistance to the cargo motion. The horizontal component of tiedown tensions also provides a direct resistance to cargo motion. The vertical component of tiedown tension acts on the carriage to increase its pressure on the track. For cargo on a truck, it would apparently increase the coefficient of friction between cargo and the deck, though in this case it was not significant because the rolling resistance of the carriage was very low. While the resistance did increase, it was often not significant until the cargo had moved a significant distance, of the order of 15-25 cm (6-10 in).

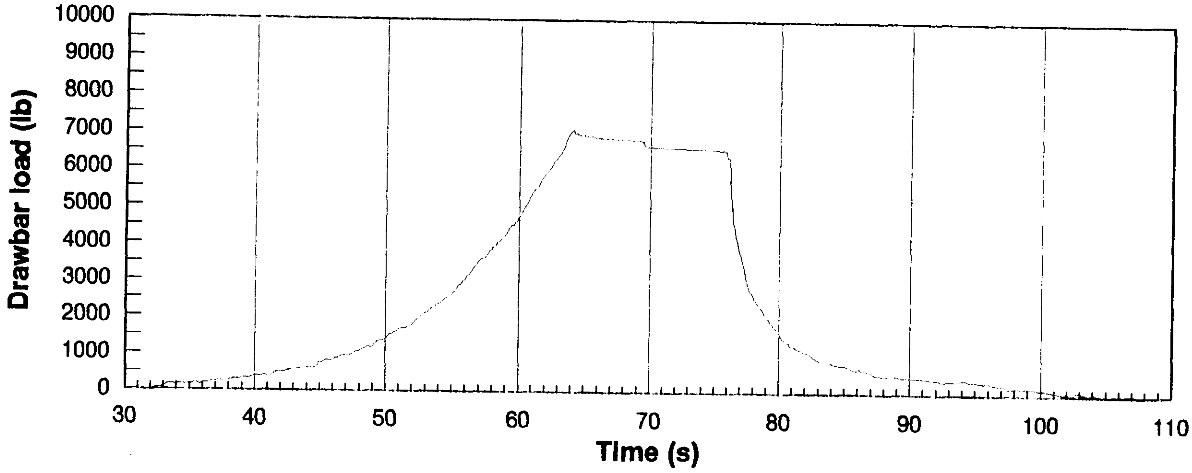
Table 4 is a summary of the results for longitudinal pulls with chain tiedowns, and Table 5 is the corresponding summary for webbing tiedowns, in the same format as Tables 2 and 3.

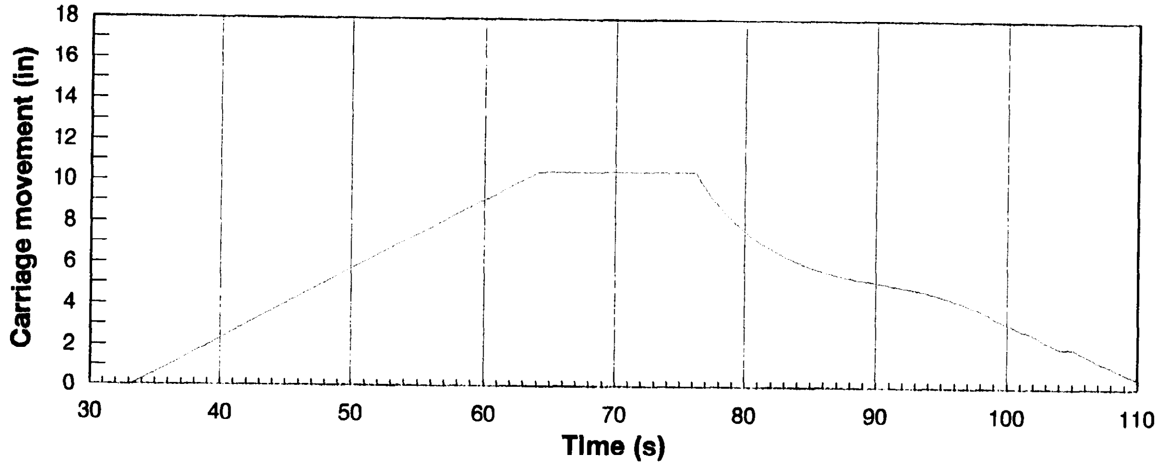
With webbing tiedowns, webbing slipped along all three types of corner, as illustrated in Figure 13. The black marks on the corner indicate the initial positions of the tiedowns. All tests were terminated by the limited stroke of the hydraulic actuator, and in relatively few cases did any tiedown reach its working load limit.

With chain tiedowns, the links on the corner immediately indented it, and in almost all cases were carried along with the carriage and never slipped back, as shown in Figure 14. In a few cases, there was minor slippage of about 6-12 mm (0.25-0.50 in) before the links indented. In some cases with wood corners the slip was larger.

The effect of initial tension is best seen in Table 4 for the chain tiedowns. As the initial tension was increased, the amount of movement to reach the tiedown working load limit is reduced, and the drawbar pull necessary to reach that limit, were both reduced. The effect of initial tension is masked for the webbing results in Table 3, because they are taken for inconsistent points during the pull, and slip occurred at different points during a pull.

The resistance provided by the tiedown is of interest. There was very little initial resistance, as the carriage was designed to provide minimal rolling resistance. For chain tiedowns, when the first tiedown reached its working load limit, the resistance was in the range 0.10-0.15 g, which was not developed until after 10-25 cm (4-10 in) of cargo movement. The resistance of webbing tiedowns was slightly higher, but took even more carriage movement to develop. It is clear that transverse tiedowns over cargo loaded longitudinally on a vehicle provide little resistance to longitudinal motion, so the cargo will tend to slide longitudinally when the vehicle brakes in the absence of other sources of resistance. Normally, coefficients of friction are adequate for braking typical in normal driving. However, where low coefficients of friction exist, cargo will be prone to shift, and the transverse tiedowns will do little to resist that shift, except to the extent that they are installed with a very high initial tension to increase the effective coefficient of friction. In such cases, either the coefficient of friction could be increased by use of rubber mats [4], or the cargo could be immobilized by blocking it against the vehicle structure.





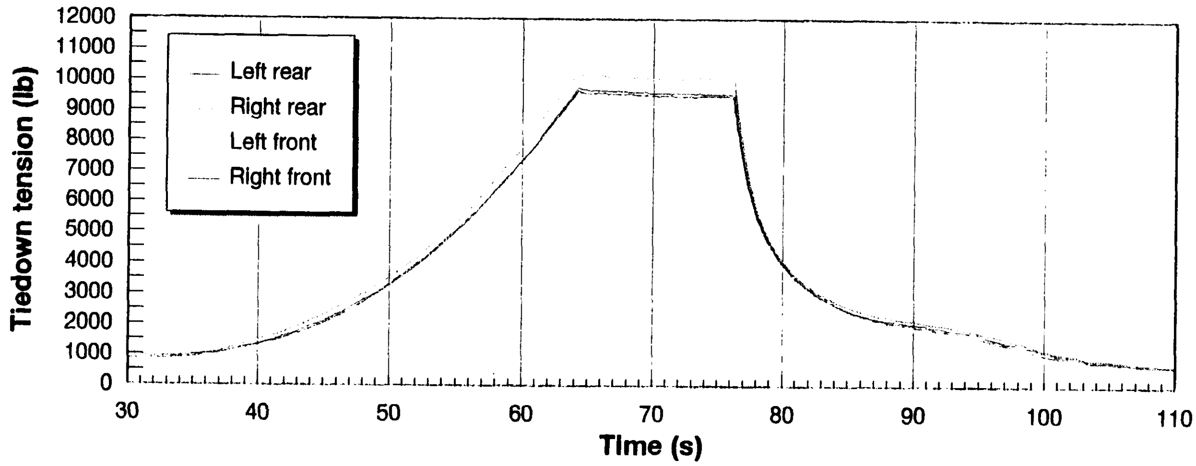


Figure 11/ Longitudinal pull with two 5/16 in grade 8 chain tiedowns 80 deg tiedown angle with 20% WLL initial tension and square steel corners

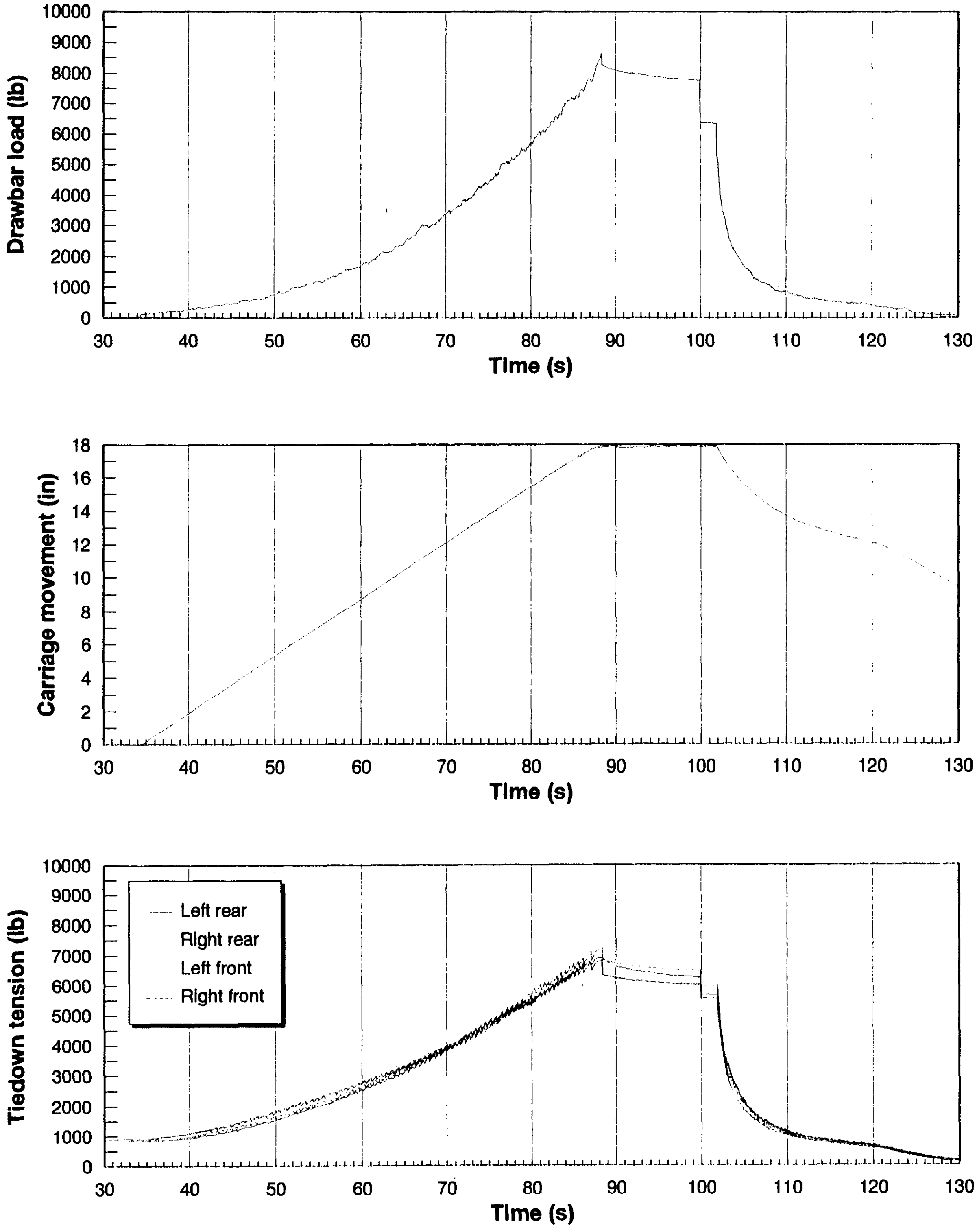


Figure 12/ Longitudinal pull with 3 in webbing tiedowns
80 deg tiedown angle with 20% WLL initial tension and square steel corners

Table 4/ Longitudinal Pull for 5/16 in grade 8 Chain Tiedowns

Tiedown angle (deg)	Corner	Initial tension (lb)	Stop	Pull force (lb)	Shift (in)	Tiedown tension (lb)	Pull equiv. g
45	R	225	WLL	2769	13.39	4512	0.154
45	R	900	WLL	2503	12.12	4505	0.139
45	R	2250	WLL	2063	9.58	4518	0.115
45	S	225	WLL	2583	12.84	4505	0.144
45	S	900	WLL	2469	11.45	4534	0.137
45	S	2250	WLL	1609	7.88	4504	0.089
45	W	225	WLL	2807	13.69	4503	0.156
45	W	900	WLL	2708	12.61	4509	0.150
45	W	2250	WLL	2083	9.38	4501	0.116
60	R	225	WLL	2465	9.84	4508	0.137
60	R	900	WLL	2160	8.62	4508	0.120
60	R	2250	WLL	1705	6.46	4503	0.095
60	S	225	WLL	1831	8.43	4509	0.102
60	S	900	WLL	1673	7.33	4535	0.093
60	S	2250	WLL	1454	5.52	4519	0.081
60	W	225	WLL	2691	11.14	4518	0.150
60	W	900	WLL	2597	9.55	4513	0.144
60	W	2250	WLL	1745	6.34	4516	0.097
80	R	225	WLL	2338	7.61	4529	0.130
80	R	900	WLL	2122	6.76	4506	0.118
80	R	2250	WLL	1760	5.22	4509	0.098
80	S	225	WLL	1983	7.37	4506	0.110
80	S	900	WLL	1847	6.15	4542	0.103
80	S	2250	WLL	1346	4.27	4521	0.075
80	W	225	WLL	2733	9.50	4512	0.152
80	W	900	WLL	2363	8.08	4509	0.131
80	W	2250	WLL	2002	6.03	4530	0.111

Note : R=round steel corner, S=square steel corner, W=square wood corner.

Table 5/ Longitudinal Pull for 3 in Webbing Tiedowns

Tiedown angle (deg)	Corner	Initial tension (lb)	Stop	Pull force (lb)	Shift (in)	Tiedown tension (lb)	Pull equiv. g
45	R	200	max	1931	17.99	2401	0.121
45	R	800	max	2392	17.97	3691	0.150
45	R	2000	WLL	2641	13.98	4011	0.165
45	S	200	max	1212	15.03	1837	0.076
45	S	800	max	1404	13.58	2518	0.088
45	S	2000	max	1968	12.13	3441	0.123
45	W	200	max	2570	18.03	2798	0.161
45	W	800	max	2674	17.54	3369	0.167
45	W	2000	max	2538	14.67	3778	0.159
60	R	200	max	3567	17.90	3384	0.223
60	R	800	max	3540	15.50	4013	0.221
60	R	2000	max	2588	10.68	4008	0.162
60	S	200	max	1677	16.20	2706	0.105
60	S	800	max	1919	17.91	3192	0.120
60	S	2000	WLL	2453	15.42	4016	0.153
60	W	200	max	2946	16.53	3409	0.184
60	W	800	max	2668	13.62	3646	0.167
60	W	2000	WLL	2503	11.00	4001	0.156
80	R	200	WLL	3865	14.25	4015	0.242
80	R	800	WLL	3390	12.07	4010	0.212
80	R	2000	WLL	2373	8.57	4025	0.148
80	S	200	max	2449	17.63	3158	0.153
80	S	800	WLL	3112	16.95	4011	0.195
80	S	2000	WLL	2382	8.55	4003	0.149
80	W	200	WLL	3904	15.41	4014	0.244
80	W	800	WLL	3277	12.76	4012	0.205
80	W	2000	WLL	2269	8.78	4001	0.142

Note : R=round steel corner, S=square steel corner, W=square wood corner.

Figure 13/ Slip of Webbing Tiedowns after Longitudinal Pull

Figure 14/ Chain Tiedowns Move with Carriage during Longitudinal Pull

5/ Analysis and Discussion

5.1/ The Longitudinal Pull

Figure 15 compares a simple model for drawbar pull and tiedown tension with the measured pull and the average tension over both sides of both tiedowns, for the pulls at the three different tiedown angles with 5/16 in grade 8 chain at an initial tension of 20% of the tiedown working load limit on round steel corners. The model has clearly captured the geometric nature of the tiedown relationship to carriage movement. It also included the effect of tiedown tension on rolling resistance of the carriage, but this is a relatively small factor compared to the direct resistance from the rearward component of tiedown tension. The key factor in matching the model and test simply was to develop an equivalent stiffness for the entire tiedown assembly, including the effects of test rig deflection and the D-rings, shackles, load cells and binders seen in Figures 1 through 4 with the measured stiffness of the chain. This was done empirically, in this case. However, it clearly shows that it should be possible to model this system quite well, provided accurate data can be obtained.

Previous work has analyzed this tiedown system in some detail [5]. It also found that transverse tiedowns provide little initial resistance to cargo movement, and concluded that they can only achieve a reasonable level of restraint if the tiedown angle is high (over 45 deg was suggested), there is a high initial tension in the tiedown, and there is a high coefficient of friction between the cargo and the deck [5]. The first two points ensure that the third, the coefficient of friction, is used most effectively. During other parts of this test program, it was found difficult consistently to produce an initial tension in webbing tiedowns even of 3.56-4.45 kN (800-1,000 lb) using a long winch bar [6]. This is of the order of 20% of the working load limit of many typical tiedowns. At this level of initial tension, and assuming the tiedown aggregate working load limit was just one half the weight of the article [3], this would result only in a 40% increase in the coefficient of friction. Other tests found it was possible to develop high tension in a chain tiedown using a ratchet binder, or a lever lock binder with a pipe over the handle to increase the mechanical advantage [7]. However, the latter is a practice not recommended by the manufacturers of this equipment.

5.2/ The Lateral Pull

The arrangement of tiedowns for the lateral pull is more complex to model, and depends additionally on the coefficient of friction between the tiedown and the cargo [5]. This study also found that transverse tiedowns provide little initial resistance to cargo movement, and concluded that they can only achieve a reasonable level of restraint if the tiedown angle is high (over 45 deg was suggested), there is a high initial tension in the tiedown, and there is a high coefficient of friction between the cargo and the deck [5].

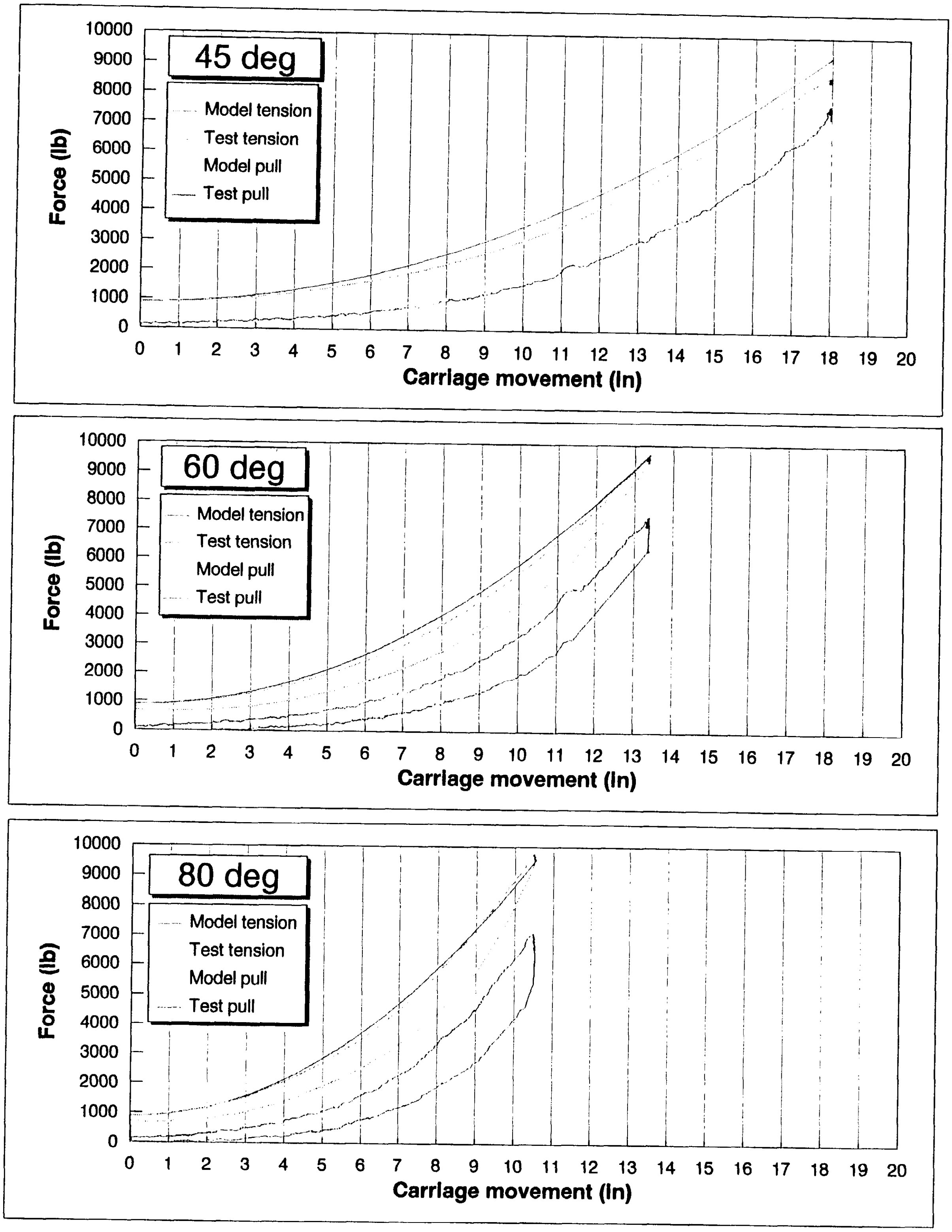


Figure 15/ Comparison of model and test
5/16 in grade 8 chain on round steel corners at initial tension of 20% of WLL

5.3/ Summary

Current regulations [3] do require an objective level of securement, but in practice it appears that this is deemed to be satisfied if an appropriate number and aggregate capacity of tiedowns are used, which depend on the size and weight of the article being secured. There is no check, nor any practical means to check, that the required number of tiedowns actually provide the required resistance.

The foregoing discussions lead to the conclusion that if the tiedown angle is low, or it is not possible to develop a high initial tension in the tiedowns and maintain it, or the coefficient of friction is low, that some additional means should be used to provide the primary longitudinal or lateral securement for the cargo. This might include immobilizing the cargo by placing or blocking it against the vehicle structure, or other cargo that is so placed, or by increasing the coefficient of friction by use of rubber mats or other equivalent means [4].

Considerable tiedown tension is lost across the corners of the cargo, and the tensions tend to diminish during the course of the trip [8]. This is why regulations require that tiedowns be checked periodically, and re-tensioned as necessary [3]. The reliability of tiedowns used in this method of securement would be increased if the tiedown assembly could take up slack as the cargo settled during the trip. Such devices have been developed for securement of loads of logs, and have worked well in that regard [9].

5.4/ Effect of the Corner of the Cargo

Chain and wire rope are examples of tiedowns that have high stiffness and a hard surface. They develop very high tension for small amounts of cargo movement, and will have a tendency to cut into cargo or dunnage which has a softer surface [2, 10]. This is not a problem, if cargo damage is not a concern, such as for pulpwood logs. It is a problem if cargo damage is a concern, so it is appropriate that dunnage or corner protection should have at least as hard a surface as the tiedown. Webbing is a tiedown with low stiffness and a soft surface. When the cargo moves, it slips and does not develop a high tension, so there is much less likelihood of cargo damage if it bears directly against soft cargo or dunnage, though it may be subject to damage if the cargo has a sharp edge [11].

This and a number of other tests in this series have all found that there is a relationship between the tiedown, its tension, and the material the tiedown bears upon, whether it is cargo or dunnage [2, 8, 10]. It is clear that some means of protecting cargo can compromise the effectiveness of the tiedown as part of the cargo securement system, and other work has suggested a set of criteria for corner protection devices that appear broadly applicable across all types of cargo [10].

6/ Conclusions

Tension in a transverse tiedown securing cargo loaded longitudinally on a vehicle is governed principally by the geometric effect of cargo movement causing elongation of the tiedown. The change in tiedown tension due to cargo movement can be determined quite well by a simple geometric model with the tiedown represented by a linear spring.

Transverse tiedowns over an article of cargo placed longitudinally on the deck of a vehicle provide very little initial resistance to either longitudinal or lateral movement of the cargo. Resistance develops as the cargo moves, but only reaches the range 0.1-0.25 g after significant cargo movement, in the range 10-46 cm (4-18 in), with the actual value depending on relationships between the geometry of the cargo, the vehicle and the tiedowns. Transverse tiedowns over an article of cargo therefore do not provide either direct or effective securement for it. Their principal benefit is that the tension in the tiedowns increases the pressure of the cargo on the deck, so increases the frictional resistance between the cargo and the deck. However, this effect is relatively marginal if there is not a large tiedown angle and a high tiedown initial tension. It is also not reliable, as tiedown tension may not be maintained at its initial value during a trip.

The rapid increase in tension in a chain tiedown with cargo movement causes it to indent slightly into the cargo as it moves longitudinally, so the tiedown does not slip significantly. The tension increases less rapidly in a webbing tiedown, and it slips along the cargo as it moves, so provides a limited restraint force. If the movement is sufficiently sustained, a chain may break. A webbing tiedown is unlikely to break, but the tension may never be sufficient to halt cargo once it starts moving, and it could slip out from under the tiedown if the external acceleration is sustained for long enough.

The relationship between the tiedown and the corner of the cargo or dunnage over which it passes may play a significant role in the behaviour of the securement system.

Current regulations are interpreted that some number of tiedowns provide adequate securement, with the number based on the size and weight of the cargo and the properties of the tiedowns. Without controls on other factors in their use, many applications probably do not achieve the resistance currently required, and at least substantial cargo movement would be expected in any emergency stop. The way that transverse tiedowns interact with cargo and the vehicle does not seem clearly understood. They would likely be more effective if principles for their use were properly explained and commonly known, and means to use them effectively were available. In the absence of this, it would certainly be appropriate to require that cargo either be immobilized, or that specific means be used to increase the cargo to deck coefficients of friction, including high tiedown tension.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report [12].

7/ Recommendations

1/ Cargo that is placed longitudinally on the deck of a vehicle and secured by transverse tiedowns should preferably be immobilized against the vehicle structure or other fittings, either directly, by use of blocking and bracing, or by placing it against other cargo that is so immobilized.

2/ If there is a low tiedown angle for an article of cargo, or it has a low coefficient of friction with the deck, or a high tiedown tension cannot be assured, then transverse tiedowns are unlikely to be adequate as the primary means of securement, and they should be supplemented by other means that will inhibit any tendency to longitudinal or lateral movement.

3/ If some article of cargo is not immobilized, the coefficient of friction between the cargo and deck or interface should be increased to reduce the tendency to shift, and a high tiedown tension should be used.

4/ Initial tiedown tension should be as high as possible, preferably at least 50% of the tiedown working load limit, to gain the maximum benefit from friction between the cargo and the deck.

5/ Corner protection should be used where a hard tiedown would bear directly onto cargo or dunnage that may be crushed if the cargo moves, and the corner protection should be as hard as the tiedown.

6/ The way in which transverse tiedowns work should be clearly explained to those that use them, so that they be used effectively.

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